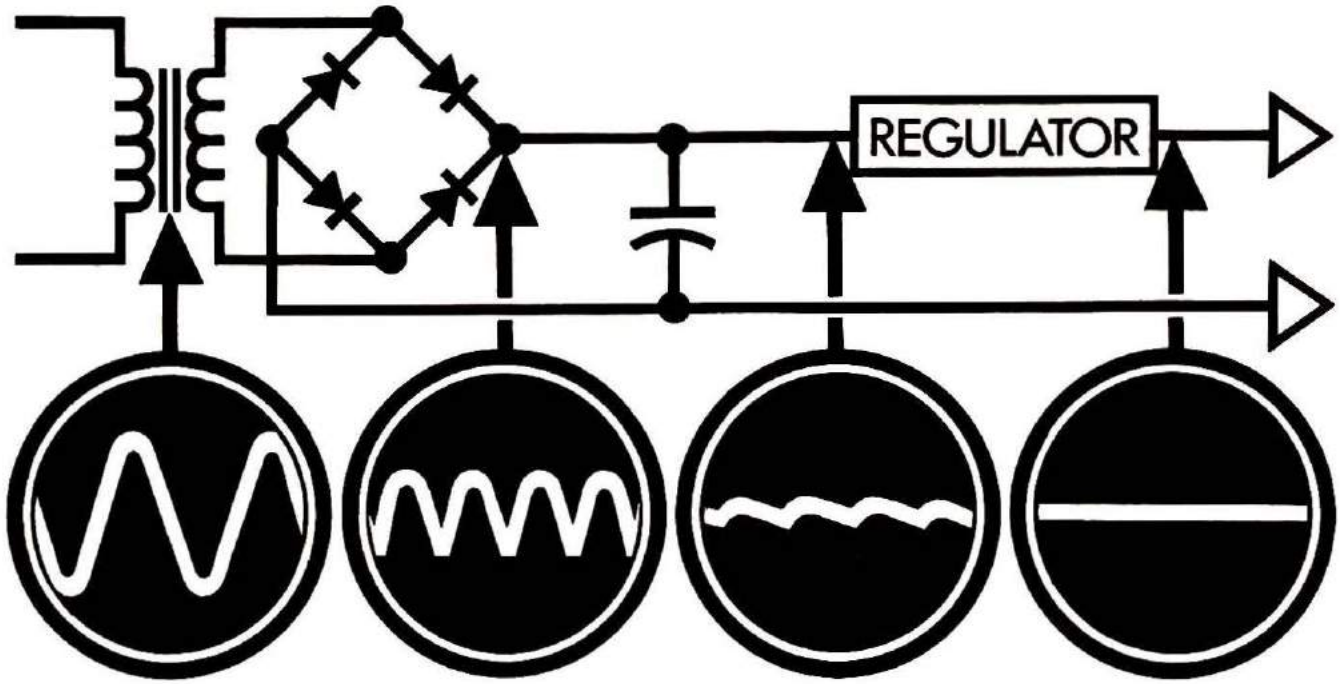


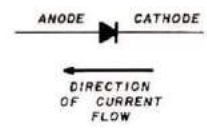
Your POWER SUPPLY--
What the 'Scope will show

BY JOSEPH CARR, K4IPV

A power supply can be said to provide the fuel that your electronic circuits run on. Most power supplies are so basic in design that it is surprising that they cause much trouble, and even more surprising that so many people have trouble understanding what the problem is. A few minutes spent with some elementary theory and following the current flow through some typical power-supply circuits will save much more time when trouble strikes. I'll start right at the beginning of a typical supply and tell you how it all fits together. So you'll be able to look for any problems, or build your own supply.

Some basics

The dc power supply converts the alternating current from the wall outlet to the direct current required by most electronic circuits. The heart of the supply is a rectifier, which may be either a vacuum tube or solid-state device. In recent equipment, of course, the latter is used. The rectifier has an important property: it allows current to pass in only *one* direction. The symbol for a diode rectifier is shown in **Fig. 1**. When the rectifier anode is positive with respect to the cathode the diode will be *forward-biased* and will pass current. When the diode's anode is negative with respect to the cathode, however, the diode will be *reverse-biased*, and won't pass current.



ANODE POLARITY WITH RESPECT TO CATHODE	CURRENT FLOW?
NEGATIVE	NO
POSITIVE	YES

Fig. 1. The basic diode rectifier symbol.

An ac waveform is shown in **Fig. 2**. This waveform is called a sine wave. Positive-going peaks in this waveform represent current flow in one direction, while negative-going peaks represent current flow in the opposite direction. When this waveform is applied to a diode, only the positive half can forward-bias the diode and thus will appear at the cathode.

Figs. 3 and **4** show two common power supplies. **Fig. 3** is a full wave supply, while **Fig. 4** shows a full wave bridge circuit. Let's first consider the operation of these circuits as if the filter capacitor (C1 in both cases) were not there.

The power supply of **Fig. 3** uses a center-tapped transformer and two rectifier diodes (typically of the 1N4000 series). On the positive half of the ac input alternation, the top of the transformer will be negative with respect to the

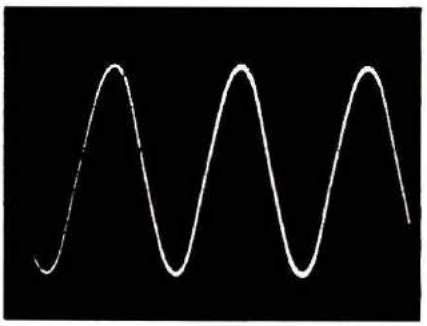


Fig. 2. Ac input waveform applied to the rectifier.

bottom. Of course, because of the operation of an inductor, we know that each turn will be slightly more positive than the turn immediately above it if we measure the potential on a turn-for-turn basis starting at the top. This means that the centertap will be positive with respect to the top end but negative with respect to the bottom end of the transformer secondary. Since it is a *center*-tap, the voltages appearing across the top and bottom halves will be equal. When the bottom half is positive, diode CR2 will be forward biased and diode CR1 will be reverse biased. This means that current will flow from the center tap through load resistor R1 then through CR2 back to the transformer. On the second alternation of the ac cycle the polarities will reverse, making the top of the transformer secondary winding positive with respect to the bottom. In this case, current flows *out* of the center tap, through R1 in the *same direction as before*, and back to the transformer secondary winding through diode CR1. The key to the success of the full wave supply is that *current in the resistor flows in the same direction on both halves of the ac input cycle.*

The bridge rectifier circuit of **Fig. 4** doesn't require a center-tapped secondary on the transformer. If the same transformer used in **Fig. 3** were used in **Fig. 4**, you'd obtain twice the output voltage but at one-half the current rating. When the top of the secondary of T1 is negative with respect to the bottom, diodes CR1 and CR3 will be forward-biased and CR2/CR4 reverse biased. Current will flow from the top of the transformer secondary through CR1, and load resistor R1, through CR3, then back to the opposite end of the transformer secondary. On the second half of the input ac waveform the situation will reverse, making the top of the secondary positive with respect to the bottom and forward-biasing diodes CR2 and CR4. Of course, CR1/CR3 will then be reverse-biased. Current will flow from the bottom of the transformer secondary through CR4 and load resistor R1 in the *same direction as before*, through CR2, and then to the top of the transformer secondary.

Since both **Figs. 3** and **4** are *full wave* supplies, the current flowing through R1 will be the same on both halves of the ac input waveform. This action produces a waveform across R1 (assuming C1 is out of the circuit!) as in **Fig. 5**.

This waveform is still not pure enough for most electronic circuits. If it were a receiver power supply a loud hum would be heard in the output.

If the supply were for a transmitter you'd receive hum reports from other amateur stations, ARRL *Official Observers*, and maybe the FCC if you're unlucky. Adding C1 (**Figs. 3** and **4**) to the circuit will help reduce the bumpiness, or "ripple component" and make the dc output more like pure dc, as obtained from batteries.

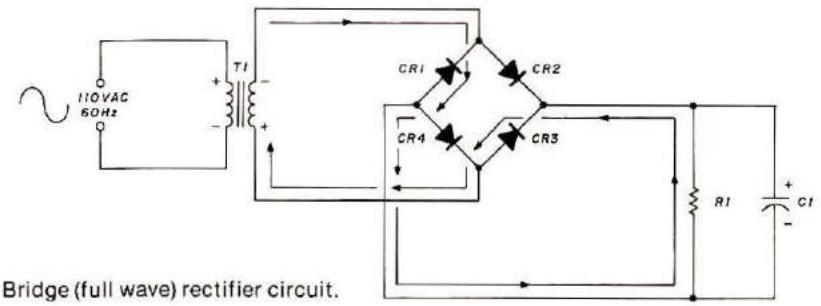


Fig. 4. Bridge (full wave) rectifier circuit.

Fig. 6 shows the waveforms associated with a full wave supply with a single filter capacitor to smooth the direct current. This is typical of most modern solid-state equipment, especially if critical stages such as the *VFO, crystal oscillator,* or *local oscillator* are fed from a regulated power-supply circuit. The waveform in **Fig. 6A** is the ac sine wave delivered by the transformer. If you placed the input of your oscilloscope across the secondary of T1 in either power-supply circuit you'd see this shape. The waveform in **Fig. 6B** is the full wave rectified voltage applied across the resistor (R1).

But since capacitor C1 is in both circuits, we find a slightly different situation, as represented in **Fig. 6C**. During

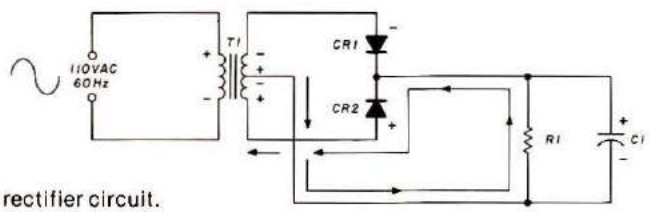


Fig. 3. Simple full wave rectifier circuit.

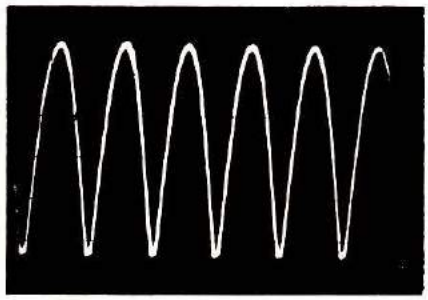


Fig. 5. Waveform across R1 if C1 is disconnected.

each hump or peak in the **Fig. 6B** waveform, capacitor C1 will charge on the upward excursion but discharges during the downward excursions. So when the rectifier voltage is increasing in amplitude, a charge will be stored in C1; but as the rectified voltage passes its peak and begins to fall, the charge from the capacitor is dumped back into the circuit. This action tends to fill in the spaces between peaks, as shown in the waveform of **Fig. 6C**. Of course, if an oscilloscope were placed across the power supply output, we'd not see the rectifier peaks but rather a ripple component riding on a dc level, as in **Fig. 6D**.

Some faults

Fig. 7A shows the waveform photographed on a scope. The waveform was at the output of a bridge-rectified power supply such as shown in **Fig. 4**. The oscilloscope horizontal sweep was set so that two cycles of the 120-Hz output saw-tooth were visible. But when either diode CR1 and CR4 opens up, you'd see the waveform in **Fig. 7B**. Because only one diode is operating, the ripple frequency will be half that normally expected.
(In any operating full wave supply, the ripple frequency is twice that of the ac mains frequency; in the 60-Hz systems used in the U.S. it will be 120 Hz.) In this case, the ripple component is only 60 Hz, indicating that one or more (of the same pair!) of diodes is open-circuited.

Although it may seem unlikely that a diode rectifier would *open*, it's fairly common in bridge circuits. With molded bridge-rectifier stacks, especially the low cost "bargain" variety, an internal connection may be broken. But in all bridges — and that includes those with four discrete rectifier diodes handwired — very often one of the diodes to the negative output line (CR1/CR4) will open if one of the other diodes becomes shorted.

Unfortunately this becomes an occult problem, because the shorted diode will cause all kinds of pyrotechnics including blown fuses. It seems that all of the initial and most obvious symptoms will occur from that shorted diode. No loud whistles will occur when CR1 or CR4 opens, but you'll find minor things like improper tuning; a loud hum (the filters were designed to work with 120 Hz, so are less effective); or off-calibration. In one case, I used the "bridge with a known good one" test to check the capacitor. When the extra capacitance was added to the circuit, the hum level decreased, so I erroneously labeled the existing filter as "bad" and replaced it . . . guess what — the hum was still there! The problem was caused by an open bridge rectifier and not by an open filter capacitor.

Replacement of solid-state rectifier diodes is one area where many amateurs go wrong. Most fail to appreciate the voltage at which the diode must operate. Let's take, for example, the common +750-1000-volt power supply used with transmitters and transceivers in the 100-200-watt class. The diode-voltage rating is the *peak reverse voltage* (PRV) or *peak inverse voltage*

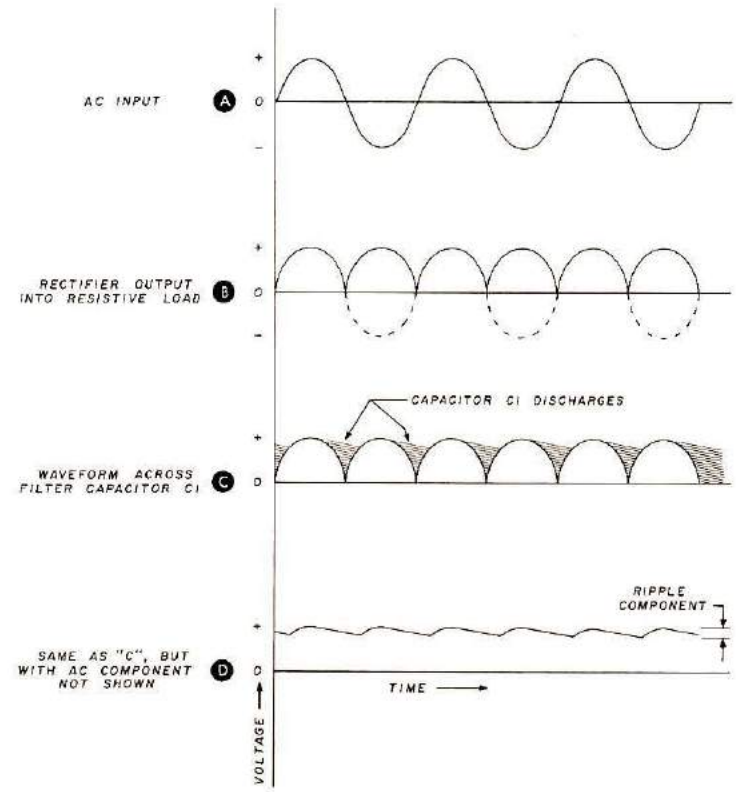


Fig. 6. Waveforms associated with either **Fig. 3** or **4** showing action of filter capacitor C1.

(PIV) (both the same). This voltage is the maximum reverse bias the diode can handle without being destroyed. If the 750-1000-volt supply is built as in **Fig. 3** the transformer will have a 750-0-750-volt secondary. This means that the voltage applied to the diode will be *1.41 x 750 = 1060 volts*. The factor 1.41 is needed because the 750-volt rating is root-mean-square (*rms*) and we want *peak volts*.

A commonly available TV replacement rectifier is rated at 1000-volts PIV, so two in series can be used, right? Wrong! To be sure, the PIV rating of the combination will be 2000 volts, which is greater than 1060 volts — so what's the problem? If capacitor C1 (**Fig. 3**) were not used, then the PIV and forward voltages would be the same — but recall that capacitor C1 charges also to the peak voltage. The actual PIV presented to the diode will be *2 x 1060 = 2120 volts*. Clearly, 2000 volts of PIV rating is not good enough, because there will be 120 volts *more* on one half of each cycle! **Fig. 8** shows the full wave supply of **Fig. 3**, which has been redrawn and simplified to illustrate this problem. In this case, the reverse voltage applied to the diode is 2 x 1.41 x the transformer rms. The correct PIV rating of the replacement diode is *not less than* E_{rms} x 2.82. Most professional servicers, who back their work, prefer to use a factor of 3 for safety and so will select a diode that is 3 x E_{rms}.

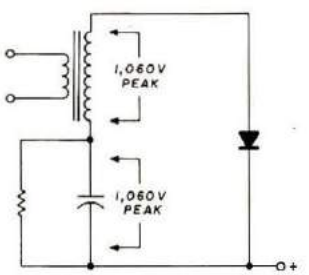


Fig. 8. Redrawn and simplified version of **Fig. 3** showing how the diode PIV is actually *2.82 x* E_{rms}.

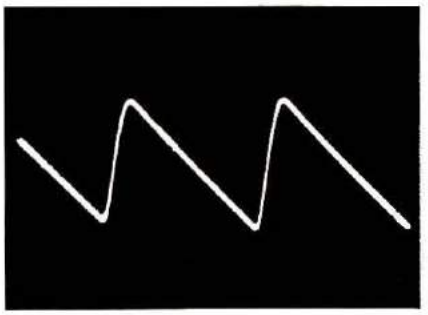
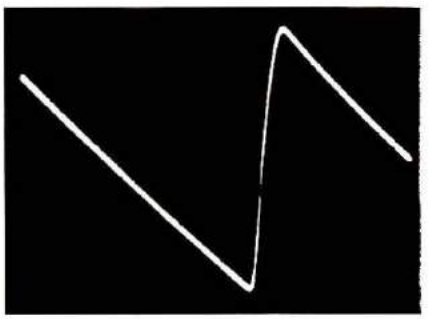


Fig. 7. Above, normal 120-Hz sawtooth from **Figs. 3** and **4**. Below, 60-Hz sawtooth if CR1 or CR4 is open.



Of course, we may still use those low-cost TV-replacement diodes, but we must adapt them as in **Fig. 9**. Each diode is a 1000-volt PIV TV replacement type. These diodes are available in the 1N4007 series at 1-ampere forward-current rating and up to 2.5 amperes in certain "house brand" types. Be a little wary of certain types apparently rated at 1 ampere, especially those of the imported variety, or when found in certain blister-pack offerings. Many of these diodes are substandard and will only withstand their rated current if the leads remain at full length to act as heat sinks.

You think I'm kidding? Ask a number of TV servicers about that! A lot of those diodes were sold to the service industry awhile back, and the sets that received them wouldn't make it through the 90-day warranty on the repair! There are no bargains, in general, so be prepared to pay a little bit for the diodes. Good 1N4007 diodes from reputable sources (see some of the advertisements in this magazine) cost only a little more than the off brands but will most likely behave themselves. It's an extreme case of penny wise and pound foolish to use less than top-grade replacement parts on that transceiver, which probably cost you almost a thousand bucks!

The resistors in **Fig. 9** balance the voltage drops across the respective diodes. It's usually satisfactory to use a value for R that is 100-ohms/volt peak applied to the stack. For full rating of the diodes, 1000 volts x 100 ohms/volt results in a value of 100 kilohms or more. Less resistance would make the circuit think that there is no diode and little in the way of rectification would occur. some sources also recommend that a 0.001 μF capacitor be placed across each diode.

Fig. 10 shows the waveform to expect in another kind of problem. **Fig. 10A** was from a bridge rectifier circuit such as **Fig. 4**. In both cases, the problem was the same: a B+ fuse placed at the rectifier output failed. Note that the waveform in each case is the rectifier output as if no filtering were present. The fuse in each case was used to protect the rectifiers in case a filter capacitor, final output tube, or other circuit element shorted to ground. The fuse was located right at the rectifier, between the load and the filters.

The waveform photos were taken at the (+) terminal of the rectifiers. An initial voltmeter check would lead you astray if made across the filters, at the

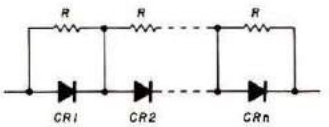
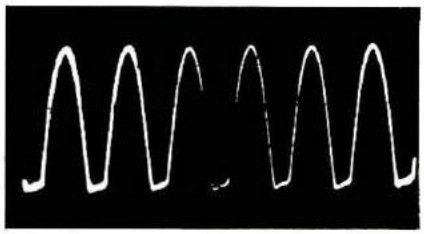


Fig. 9. TV-replacement rectifiers can be stacked to gain a higher PIV rating that might be needed in a transmitter.

transmitter final amplifier (rf choke), or other point beyond the fuse. One might say "Aha! A bad power supply!" and spend a great deal of time trying to figure out why the supply is no good. The real culprit, however, might be external to the power supply.



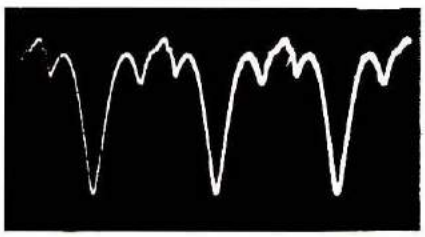


Fig. 10. Waveforms at the output of full-wave rectifier, above, and bridge rectifier, below, if a rectifier fuse is blown (see text).

For example, in many transmitters, if the oscillator or a buffer stage fails the final amplifier tubes will be unbiased and will run red hot. This means that an overload current is being dragged out of the power supply, so a fuse might blow — if you're lucky.

B+ fuses often seem to be located on the chassis rather than be accessible from the outside; I don't know why but it's a fact. So look for a fuse either in a chassis (open) fuse holder, or a pigtail fuse wired into the circuit. At the risk of repeating myself from earlier articles, let me point out once more that a fuse doesn't cause trouble, it *indicates* trouble! If a serviceman charges you beaucoup bucks for repairs that could have been simple, except that you installed an oversized fuse to stop the "blowing" problem, then you're up for *fair game*! **HRH**

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